Monitoring Fire Effects and Vegetation Recovery on the Jasper Fire, Black Hills National Forest, SD

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In late August and early September 2000, the Jasper Fire burned an area of ~33,800 ha or ~7% of the Black Hills National Forest, SD. This was the largest recorded fire in the history of the Black Hills. The Jasper Fire burned under a variety of fuel and weather conditions creating a mosaic pattern of tree mortality in patches of varying size and extent. The fire completely blackened some areas, leaving scorched, dead trees, no aboveground herbaceous vegetation, and ash-covered ground. Other areas experienced only a light surface burn with tree trunks and lower branches scorched, islands of herbaceous survivors, and a patchy residual litter layer. Some areas were completely unburned. The fire burned in a variety of habitats under varying topographic conditions both in open meadows and in stands of different composition, age, structure, and density. It is important to monitor the effects and interactions of the fire on the ecosystem and to develop guidelines for restoration because most of this fire occurred in forests that have been intensively managed for a long time.

The Jasper Fire provides an opportunity to observe the influence of pre-fire vegetative conditions, fire size, and consumptive patterns on post-fire ecological succession in the Black Hills. This fire is similar to other historical fires in interior forests in that it was an extensive, late season burn. As a result of weather, topographic, and fuel conditions, the Jasper fire created a mosaic of burn intensities (amount and rate of fuel consumption) and severities (fire effects on the ecosystem) of varying patch size and areas of unburned vegetation across the landscape. Given the spatial extent and heterogeneity of the burn we can address questions relating to fire behavior, temporal and spatial patterning, and subsequent effects on recovery processes. From a practical perspective, an understanding of why particular trees die and what we can expect in terms of recovery based on different fire effects may be useful in mitigation/planning. Value recovery restoration activities provide an opportunity to monitor the effects of salvage harvesting on these same processes.

Landscapes are often defined by their fundamental characteristics of structure, function, and change (Turner 1987). As part of the monitoring effort, we identified representative patches of ecosystems within the burned landscape where we can examine how the arrangement and attributes of patches influenced and were influenced by the Jasper Fire. In this pursuit, monitoring efforts address individual species and stand-level components, and examine the influence of landscape patterns or patch mosaics on subsequent recovery processes. As landscapes are dynamic, but change does not occur simultaneously or at the same rate, we are monitoring the mechanisms responsible for the development of landscape heterogeneity over time.

Monitoring will address three areas, including fire behavior relative to pre-existing conditions; the direct, direct delayed, and indirect effects of the fire; and processes of recovery in unmanaged and restored areas, aspen stands, and montane grasslands. We will provide: (*1*) an assessment of the pre-burn structure and stocking of trees and coarse woody debris, understory vegetation composition and cover, and forest floor and soil characteristics within the fire perimeter, (*2*) a determination of the post-fire effects on trees and understory vegetation, microclimates and soils, and (*3*) an examination of recovery processes, in particular, the extent that natural tree regeneration, the soil seed bank, and resprouting individuals may contribute to vegetative recovery. Monitoring efforts will stimulate research pertaining to the relationship of recovery patterns to general models of forest condition. Understanding how silviculture and other past management activities influenced this fire's behavior will facilitate development of predictive tools to aid restoration and plan future management activities to reduce the risk of large-scale catastrophic fires occurring elsewhere in the Black Hills.

Monitoring Questions:

1) ***What is the relation between fire behavior and direct effects of the fire on vegetation and soil?***

2) ***How does the rate of recovery vary in areas of different fire behavior?***

Experimental Approach to Monitoring

Answering these questions involves addressing the physical effects of the fire upon vegetation, documenting natural vegetation recovery from the fire disturbance, and assessing the effectiveness of short-term management efforts to speed recovery, mitigate adverse effects, or salvage timber within the burned area. Meeting these objectives requires a monitoring design that can accommodate the large size of the fire, the diverse nature of disturbance to vegetation within the fire, and the magnitude and timing of on-going salvage and recovery activities.

In contrast to other recent fires in the ponderosa pine type, the Jasper fire occurred in an area that contained a fine-scaled mosaic of vegetation structural stages and burned in a manner that produced an overlaying mosaic of burn severities, ranging from complete mortality of aboveground vegetation, to no disturbance at all. Although most of the vegetation within the fire is dominated by ponderosa pine (*Pinus ponderosa* Dougl. ex P. & C. Laws.), scattered aspen (*Populus tremuloides* Michx.) clones and montane grasslands (elevations > 2000m) are also an important component of the ecosystem. In addition, large portions of the burned area were scheduled for salvage or other recovery under existing timber sale contracts. All of these factors were accommodated in the monitoring of vegetation recovery. This report will present data from five years of monitoring in ponderosa pine stands that did not receive post-fire silvicultural treatments.

The difficulty of coordinating management and monitoring activities across all disciplines to maintain the integrity of plots scattered throughout the fire perimeter continues to be of concern. Existing forest GIS and RIS databases, project plans, and input from the fire recovery ID team were

used to identify areas within the fire that could be dedicated to monitoring activities. These areas had to be large enough to represent vegetation recovery processes at an ecosystem scale, yet diverse enough to typify vegetation conditions throughout the area both before and after the fire.

After meeting with the Jasper fire ID team, a design was selected utilizing three monitoring areas in the north, central and southern portions of the Jasper fire. Management activities in these ~800 ha reserve areas were limited to roadside hazard tree removal and spot spraying of noxious weeds. Three additional geographically-paired monitoring areas were identified where salvage and other recovery activities occurred. Monitoring areas were used to gage the impacts of management activities on post-fire recovery. Recovery of timber value was limited to areas that burned under moderate and high intensities. Aspen clones and montane grasslands were monitored in the central and northern locations within the fire perimeter as these types of vegetation are extremely rare in the southern portions of the fire. Dedicating relatively small portions of the fire area to monitoring activities insures that recovery and resource management activities can proceed throughout the majority of the fire area without conflicting with monitoring plots, personnel, or equipment. In addition, this design provides sufficient statistical reliability to extrapolate results to the entire fire area.

Using color infrared aerial photography and a GIS-based map of canopy scorch as guides, we located areas of different fire behavior according to ground-based visual assessments of fire effects on residual vegetation and litter **(Table 1)**. Following fire, the appearance of vegetation, litter, duff, and upper soil horizons can be used to estimate the amount of heat radiated downward into the underlying duff and mineral soil (DeBano and others 1998). The magnitude of the observed change depends largely on the severity of the fire. Severity has been defined in several ways depending on the focus of the study. In its most general sense, severity refers to ecosystem

response to fire (DeBano and others 1998). Fire severity is usually classified as light (surface burn), moderate (severe surface burn), or high (crown fire) (DeBano *et al.*, 1998; Ryan and Noste, 1983; Turner *et al.*, 1994), and is roughly the product of fire intensity and residence time. Fire severity has been based on the amount and location of organic matter lost by burning, decreases in the protective forest floor, volatilization of nitrogen and other elements, and transformation of less volatile elements to soluble mineral forms (Wells and others 1979). Fire severity may also relate to the degree that on-site plants survive a fire or reproduce from on site meristematic tissue such as rhizomes, root crowns, underground stems, and seeds or the extent to which the site is invaded by seed from off-site plants (Lyon and Stickney 1976). Within the context of a larger monitoring design, we quantify direct fire effects, provide a characterization of severity in terms of fire effects on soil and vegetation, and assess rates of nutrient and vegetation recovery in areas of different fire behavior during the first three years following this large wildfire. Since recovery processes may proceed at different rates as influenced by landscape position, high fire behavior sites were established at 0 (high-0m), 50(high-50m), and 150 m (high-150m) distances from the live edge or potential seed source. All sites were replicated three times within each fire behavior class within three locations **(Table 2)**. Geographically-paired unburned sites were established to provide a reference for pre-fire conditions.

Table 1. Description of fire effects and anticipated recovery processes in areas of different fire behavior.

Fire Behavior Classes	Low	Moderate	High		
			Edge(0m)	Close (50m)	Remote (150m)
Percent of fire area classified by severity	27	48	25		
Type	Surface	Mixed surface & crown	Mixed surface & crown	Crown	Crown
Description	Needles green/ scorched; litter scorched/ consumed; Duff intact, Mineral soil unaltered.	Needles killed, but not consumed; litter & duff largely consumed. Soil covered by dead leaves fallen from the canopy. Mineral soil not visibly altered. Residual fuel deeply charred.	Trans-itional	Needles of canopy trees completely consumed by fire; soil organic layer almost entirely consumed. Soil is bare with no litter. Mineral soil reddish or orange. Deep ground charring.	
Initial Aboveground Mortality	Patchiness in Understory	Patchiness in Understory & Overstory	Understory & extensive Overstory		
Distance to Live edge	0 m	< 10 m	0 m	< 50 m	> 100 m
Recovery Processes	Variable	Variable	Variable	Influenced by proximity to seed source in living plants	

Table 2. Site descriptions and experimental design.

		Number of sites
No Post-fire Silvicultural Activities	6 Fire Behavior Classes X 3 Locations X 3 Reps	54*
Post-fire Silvicultural Activities	2 Severity Classes X 3 Locations X 3 Reps	18*
Aspen	(2 Severity Classes X 2 Locations X 3 Reps) + (1 Unburned Class X 2 Locations X 1 Rep)	14**
Grasslands	(1 Burned Class X 2 Locations X 3 Reps) + (1 Unburned Class X 1 Location X 1 Rep)	7

NOTE: * 0.28 ha sites, ** 0.03 ha sites.

Classes = Fire Behavior (Unburned, Low, Mod, High - 0m from live edge, High - 50m from live edge, High-150m from live edge)
Locations = North, Central, South
Replicates = 1, 2, 3 sites
Sites = 1, 2, 3 plots

Methodology

- **Year 1**
  Establish permanent monitoring sites (Appendix 1)
  Measure direct fire effects in areas of different fire behavior on the following:
  - Overstory vegetation - tree mortality and foliage, bole, and basal scorch, general stand structure characteristics (e.g. DBH, height, crown base height).
  - Understory vegetation - woody & herbaceous species composition, cover and richness
  - Forest floor - litter, fine fuels, and large woody biomass
  - Soil - physical and chemical assessments including available nitrogen analysis

- **Years 2- 3**
  Assess recovery in areas of different fire behavior on the following:
  - Overstory vegetation - additional tree mortality and insect activity
  - Understory vegetation - woody & herbaceous species composition, cover and richness
  - Forest floor - litter, duff, fine fuels, and large woody biomass
  - Soil - continued monitoring and measurement of available nitrogen within burned and unburned pine sites.

- **Years 4-5**
  - Overstory vegetation - additional tree mortality and insect activity
    - 2005 remeasure DBH, height, crown base height.
  - Forest floor - litter, duff, fine fuels, and large woody biomass
  - Soil - continued monitoring and measurement of available nitrogen within burned and unburned pine sites.
  - Understory vegetation - woody & herbaceous species composition, cover and richness

Measurements

Overstory Vegetation Measurements:

In 2001, we installed seventy-two 0.28 ha sites in pine stands. At each site, we tagged every tree ≥ 1.4m tall within three 0.03 ha plots. For every tree, we recorded species, live/dead status, DBH, tree height, pre-fire crown base height, bark thickness, cone presence, and evidence of insect activity (boring holes or dust, frass, and pitch tubes). Crown base height was determined as the lowest complete whorl and was measured to the height of attachment to the bole. In burned areas, we determined the prefire crown base height by the location of scorched needles and(or) fine branch structure. Distance and azimuth from the site center to the northernmost tree was recorded. Sites were permanently marked and coordinates were recorded with a Garmin and Trimble GPS unit. Permanent photo points were established at each site center in cardinal directions (see DVD).

To assess direct fire effects, we measured crown scorch, crown consumption, bole scorch, basal scorch and basal char on individual trees. Minimum and maximum heights of crown scorch and crown consumption delineate a zone of scorch and a zone of consumption. The portion of the crown scorched or consumed within respective zones was visually estimated to the nearest 5%. The percent of the pre-fire live crown affected by scorch or consumed by fire was calculated from these measurements. The percent of the bole affected by scorch was calculated relative to total tree height. Basal scorch and basal char assessments were based on visual estimates of the percent of the bole circumference either scorched or charred at heights less than 30 cm. Scorched bark was intact and gray-black in color, with distinguishable furrows, and a flaky texture. Charred bark was often partially eroded by fire and metallic black in color, with undistinguishable furrows, and texture similar to that of charcoal.

We estimated beneath-canopy light intensity by measuring light flux density with a sunfleck ceptometer (Decagon Devices, Inc., Pullman, WA). Readings were made in each cardinal direction at 30 points in each site and averaged for each of 9 sites per severity. Readings taken in a nearby forest opening or clearing with an unobstructed view of full sunlight were assumed to represent above canopy readings. "Open" readings were obtained every 15 minutes and averaged over the sampling period. Light sampling was conducted on sunny days between 1000 and 1400 hr MST during August, 2001. These readings provide an estimate of the amount of canopy disruption in areas of different fire behavior which may have important implications for seedling establishment and survival.

In 2002-2005, we relocated tagged trees and assessed mortality, cone and pitch presence, and insect activity. In 2005, only signs of mountain pine beetle infestation were recorded on study trees in unburned, low, and moderate fire severity study sites. In 2005 DBH, height, and crown base height were remeasured on all live trees. Canopy light readings were repeated throughout the 2002-2005 time period.

In 2001 in each aspen stand, we GPS plotted the site center of each ~0.03 ha-fixed plot (10 m radius). Every tree ≥ 1.4 m in height was tagged with an identification number located at DBH facing plot center. Distance and azimuth from the site center to the northernmost tree was recorded. For each tree within sites, we recorded species, live/dead status (noting pre-fire snag status), tree height, pre-fire crown base height, conifer bark thickness and cone presence, and evidence of disease or insect activity. Direct fire effects were assessed similar to that in the pine stands. In 2002-2005, for each tagged tree, we assessed live/dead status, conifer cone and pitch presence, and evidence of disease and(or) insect activity (cankers, gall, conks, etc). In 2005 DBH, height, and crown base height were remeasured on all live trees.

Understory Vegetation Measurements:

In 2001 and 2002, vegetation (grass, forb, seedling, and shrub) inventories in unmanaged and managed areas were conducted at two times to capture early and late season response. In 2003 and 2005, vegetation inventories were conducted one time during the middle of the summer. Vegetation measurements were not conducted in 2004. Measurements were collected at six points with a $0.25m^2$ frame w offset 2 m north at 10 m intervals along a 60 m E-W line transect centered on the site center in pine stands. Within the graded frame, the plant species or cover type (exposed mineral soil, litter, rock, or coarse woody debris) was recorded. Visual assessment of percent cover was assigned to each species or cover type within the frame. Seedlings were mapped and height and diameter measured within the vegetation plots. Shrubs were also recorded by species, distance of canopy intercept, stem diameter and height along 40 m (10-30m) of the E-W line transect.

In 2002, in ponderosa pine stands, ~10 specimens per site of each species found in understory plots were destructively sampled to determine whether individuals survived the fire or germinated post-fire. Root mass and scorch marks were the basis for criteria. The relative percent of post-fire germinants and survivors was totaled by location and fire behavior class for each species. In addition, in 2001 and 2002, in ponderosa pine stands with no post-fire silvicultural activities, sixteen aboveground biomass samples ($0.025\ m^2$) were collected off-site. These samples were analyzed for carbon and nitrogen content.

Between 2001 and 2003 and again in 2005 four $0.25m^2$ vegetation inventory plots were offset 5 m from site center in the cardinal directions in all aspen monitoring stands. In 2001 and 2002, understory and shrub inventories were conducted two times in the early and late growing season. In 2003 and 2005, understory and shrub inventories were conducted one time. No vegetation measurements were taken in aspen stands in 2004. Within the graded frame, the plant

species or cover type (exposed mineral soil, litter, rock, or coarse woody debris) was recorded. Visual assessment of percent cover was assigned to each species or cover type within the frame. In 2001-2005, all aspen sprouts <1.4 m in height were counted within a 2 m radius circular plot at site center. Shrubs were recorded by species, distance of canopy intercept, stem diameter and height along the 20 m N-S line transect. In 2002, species identified within plots were destructively sampled off-site to determine whether the individual survived the fire or germinated post-fire. In 2002 in each aspen stand, aboveground biomass samples (0.025 m^2) were collected at 16 off-site points.

In 2001 and 2002, twelve 0.25m^2 vegetation plots were surveyed at 10 m intervals along a 60 m E-W and a 60 m N-S line transect centered on the site center in montane grassland areas. Within the graded frame, the plant species (grass, forb, seedling, or shrub) or cover type (exposed mineral soil, litter, or rock) was recorded. Species density was recorded within the frame. A visual assessment of percent cover was assigned to each species or cover type within the frame.

Soil Seed Bank

In 2001, soil seed bank samples were collected from 6 locations (2 per overstory plot at 5 or 10.5 m at 90° and 270° from plot center) within each 0.28 ha site in pine sites. Soil seed bank samples were collected from a 0.025m^2 surface area to a depth of 10 cm (~2560 cm^3 $\pm$ large rock volume). Samples were collected with a hand spade, placed in paper bags, labeled by sample location, and oven-dried at 30°C. Seeds were collected from known flowering species.

In late December 2001, all soil seed bank samples and seed collections were transported to a cold storage facility at the CSU Seed Laboratory. Samples were stored at 4° C for nine months. In September '02, we prepared samples using modified methods as described by Ter Heerdt *et al.* (1996).

In the greenhouse, prepared samples were spread in a 3-5mm layer on gauze-covered vermiculite in plastic trays (20"X 10.5"X 2.5"), and kept under conditions known to promote the germination of as many species and individuals as possible. Samples were kept moist by regimented watering from below through the use of shallow tubs. Similarly-prepared control trays were placed with the samples as a check on contamination by wind-born seeds.

Tray emergents were transplanted to individual pots to eliminate competitive interactions and cultivated until identification to the species level was possible. Pots were placed on an automatic watering system and natural growing season light requirements were artificially simulated. When no further germination was detected in the trays, we dried and remixed samples to facilitate germination of buried, viable seeds. The seed bank study ended in May, 2003, when no further germination was detected.

Forest Floor Measurements:

In 2001-2005, we measured litter and duff depth at 2 m intervals along the 60 m E-W line transect. Depth measurements were made twice during 2001 and 2002, and once throughout the 2003, 2004, and 2005 growing season. In every year between 2001 and 2005, litter samples (0.025 m^2) were collected at 6 points offset 2 m/ 3m/ 4m/ 5m/6m to the south of the E-W transect located at 10 m, 20 m, and 30 m from the site center. In 2001, depth and percent low, moderate, and/or high ground char (Ryan and Noste, 1983) were recorded for each sample. In 2002-2005, depth (litter and duff) measurements were recorded for each sample collected. Forest floor samples were oven-dried, weighed, and combusted to correct for soil weight in 2001-2005.

Three litter traps were installed in 2001, 8 m from center at 0°, 120°, 240°in each of the 3 overstory plots in every ponderosa pine site. Contents were collected during August, sorted, and weighed by component (needles, cones, twigs, pine cones, etc.) between 2001 and 2005.

In aspen stands, we measured litter and duff depth at 2 m intervals along the 20 m E-W line transect. In 2001-2005, forest floor samples (0.025 m^2) were collected at 6 points offset 2m/3m/4m/5m/6m to the south of the E-W transect located at 6 m, 8 m, and 10 m from the site center. In 2001, we assessed depth and ground char for each sample. In 2002-2005, depth measurements (litter and duff) were made for each sample. Forest floor samples were oven-dried, weighed, and combusted to correct for soil weight. Three litter traps were installed in 2001, 8 m from center at 0°, 120°, 240° in each aspen site. Contents were collected in August, sorted, and weighed by component in all years.

We installed four mesh bags containing 5g of singed litter 8 m from plot center at 0°, 120°, 180°, and 240° in pine sites. Empty mesh bags were installed at one site per fire behavior class in each location. The change in litter mass over 2 years will be used to calculate decomposition rates (Olsen 1963).

In 2001, ground char assessments (Ryan and Noste, 1983) were made at 2 m intervals along the 60 m E-W line transect in montane grassland areas. In 2001/2002 in montane grassland areas, litter and duff depths were measured at 2 m intervals along the 60 m E-W line transect. Floor samples (0.025 m^2) were collected and litter depths measured at 6 points offset 2 m/3m to the south of the E-W transect located at 10 m, 20 m, and 30 m from the site center. In both years, forest floor samples were oven-dried, weighed, and combusted to correct for soil weight. Montane grasslands were not revisited after 2002.

Coarse Woody Debris (CWD) Measurements:

In all 5 years, we estimated fine fuels and downed woody biomass using the planar intersect method described by Brown (1974) and Brown and Roussopoulos (1974). We estimated the amount of pre-existing woody biomass by sampling unburned areas. We measured all dead and downed woody biomass >7.62 cm in diameter along the entire length of the 60 m transect (20 m N-S transect at aspen sites). Material <7.62 cm in diameter was measured at a total of 10 m along the transect (5 m at aspen sites). Diameter, length, and distance of intercept along the line transect were measured in 2001 and 2002. In 2003, 2004, and 2005, we measured diameter of large and small woody biomass. Coarse woody debris (CWD) > 7.62 cm was placed into decay classes of sound or rotten. Total Mg ha^{-1} of fine fuels and large woody biomass were estimated according to Brown *et al.* (1982).

Soil Measurements:

In 2001, six metal posts were installed (average height of ~0.915 m above ground) at ~15 m intervals along midslope position at selected sites within pine stands. In 2002 and 2003, measurements were collected at the base of each post and averaged to provide an index of soil loss or gain for the site. Erosion measurements were not taken in 2004 or 2005.

In 2001 and 2002, soil was collected from 6 locations within each site in pine stands. In 2001and 2002, four samples were collected in each aspen stands. In 2001and 2002, four samples were collected from each montane grassland site. Soil samples were collected from a 0.025 m^2 surface area to a depth of 10 cm (~2560 cm^3 $\pm$ rock volume). Soil samples were oven-dried at 60°C. Textural and nutrient analyses (C:H:N) were performed on these samples in 2001. Nutrient analysis (C:H:N) was performed on samples collected in 2002. Soil sampling was not repeated between 2003 and 2005.

Resin bags were installed in 2001, collected, and replaced in 2002, 2003, 2004, and 2005 in all ponderosa pine monitoring control sites. Resin bag analysis provides a relative index of nitrogen availability in areas of different fire behavior within pine stands. Four resin bags were installed at 0°, 90°, 180°, and 270° 5m from plot center in each overstory plot in unburned pine stands and those with no post-fire silvicultural activities. Three resin bags were installed at 0°, 135°, and 225° 5m from plot center in each plot within pine stands with post-fire silvicultural activities. Resin bags are made of nylon stocking material, and contain 14 mL of anion exchange resin and 14 mL of cation exchange resin, for a total exchange capacity of 20 to 25 $mmol_c$ of anions and of cations. Ammonium and nitrate will be extracted from the resin bags with 100 mL of 2M KCl. Recovery of standard additions to resin bags will determine the percentage of ammonium and nitrate that was incompletely extracted from the resin bags (Binkley *et al.* 1995).

Seedling Regeneration Measurements:

In all 5 years, we conducted regeneration surveys in 50 temporary regeneration plots (1.0 m^2 frames). These plots were randomly located throughout and around every pine site. Within each frame, we counted the number of seedlings < 1.4 m in height and, in every year except 2001, determined seedling age.

In 2001, two covered seed traps were installed 5m from plot center at 90° and 270° in each overstory plot within pine sites. Uncovered traps were paired with covered traps at 270° in one site per fire behavior class in pine sites. Uncovered traps were paired at 270° in every unburned pine site. In the following years, seed traps were emptied and replaced for collection the following year. In 2002-2005, contents collected from the seed traps were sorted into viable and nonviable pine seeds and counted in the laboratory at Colorado State University.

Preliminary Findings:

I. Pre-fire Conditions

Unmanaged Pine Sites

Our study sites were well-stocked, mature ponderosa pine stands. Pre-fire stand structure was similar in unburned and burned pine stands (**Figs. 1-3**). Average stand diameter (ASD) was 22.1 cm. Tree densities averaged 718 trees ha^{-1}, average basal area was 24.7 $m^2 ha^{-1}$, and relative density was ~0.46. Stand structures were not significantly different in terms of tree size and density across unburned and burned sampling areas (p>0.05); therefore, differences between prefire conditions and post-fire conditions are the result of fire effects.

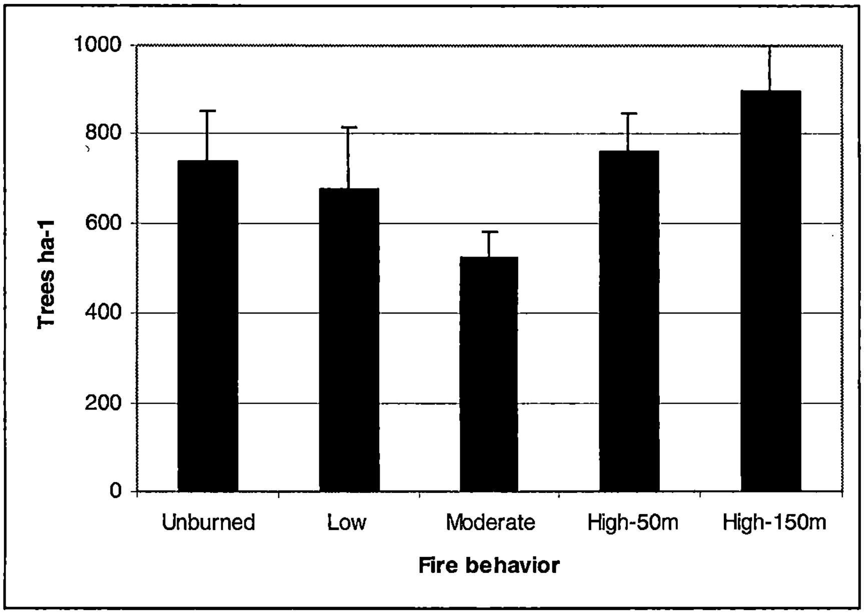

Fig. 1. Prefire density (trees ha^{-1} of trees with DBH ≥ 5cm) (mean ± 1 SE) in unburned pine stands and those with no post-fire silvicultural activities.

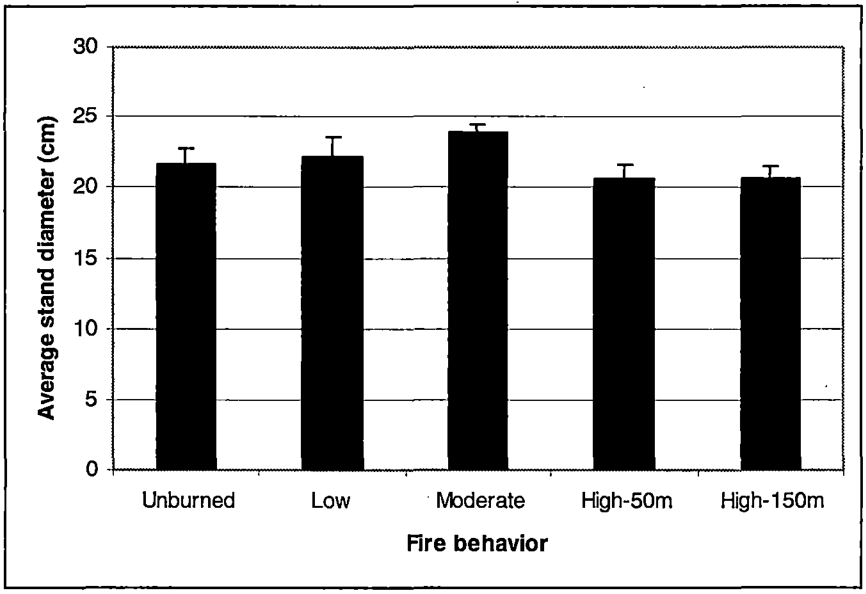

Fig. 2. Average stand diameter (cm) (mean ± 1 SE) of trees DBH ≥ 5 cm in unburned and burned pine stands with no postfire silvicultural activities.

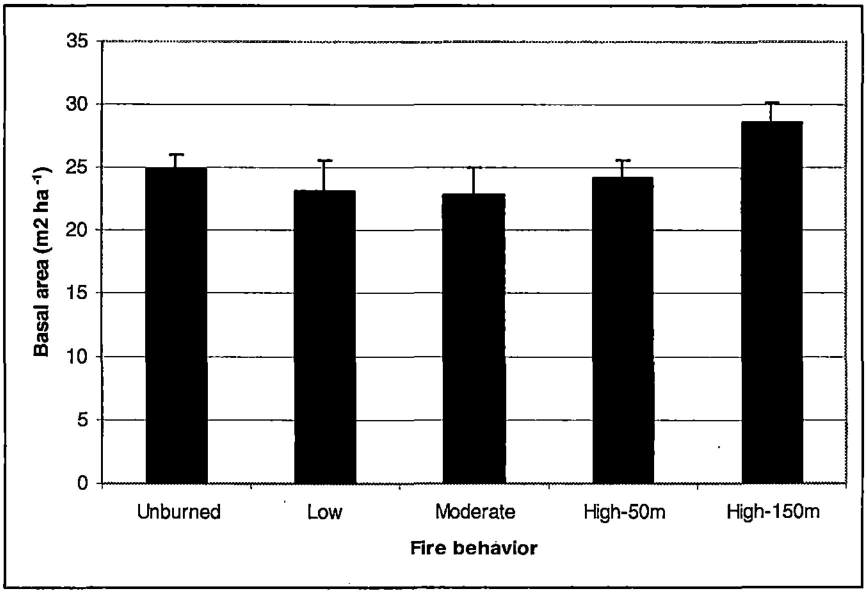

Fig. 3. Basal area (m^2ha^{-1}) (mean ± 1 SE) of trees ≥ 5cm DBH in unburned pine stands and burned stands with no post-fire silvicultural activities.

II) Direct Fire Effects

1) Fire effects and recovery in the overstory

We measured direct fire effects on ~3700 ponderosa pine trees in stands where post-fire management activities were limited to spot spraying of noxious weeds and roadside hazard tree removal. We quantified fire effects on live and dead trees in areas of different fire behavior in 2001. We assessed mortality and insect activity on tagged trees in every year between 2001 and 2005.

One year post-fire, we observed ~1(0.4), 22(5), and 100%(0) mortality (SE) as a function of prefire stand density in areas affected by low, moderate, and high fire behavior. Two, three, and four years post-fire, we observed a ~8, 7, and 2 % annual increase in tree mortality in areas of low fire behavior. The average percent mortality in areas where low severity fire occurred remained unchanged between 2004 and 2005 at ~18%. Two, three, and four years post-fire, we observed a ~16, 21, and 5 % annual increase in tree mortality in areas of moderate fire behavior. We observed only a slight increase in mortality of ~2% between 2004 and 2005 in areas of moderate fire behavior which resulted in a 5-year mortality rate of ~66% in these moderately burned areas. The significant decrease in mortality in areas of moderate fire behavior and complete cessation of mortality in areas of low fire behavior suggests that fire caused mortality as a result of direct fire effects is no longer distinguishable in these burned stands. The majority of fire-related tree mortality occurred between 2001 and 2003 with 2002 possessing the greatest amount of postfire tree death **(Fig. 4)**.

Fire selectively killed smaller diameter trees in areas of low and moderate fire behavior, and smaller trees tended to died one year post-fire. In 2001, the average stand diameter of fire-killed trees ≥ 5 cm DBH was 6.5, 16.2, and 21.1 cm in areas of low, moderate, and high fire behavior. No trees, independent of diameter, survived in areas of high fire behavior. This observation suggests

that a threshold may exist between diameter and fire survivability in low and moderate severity fires.

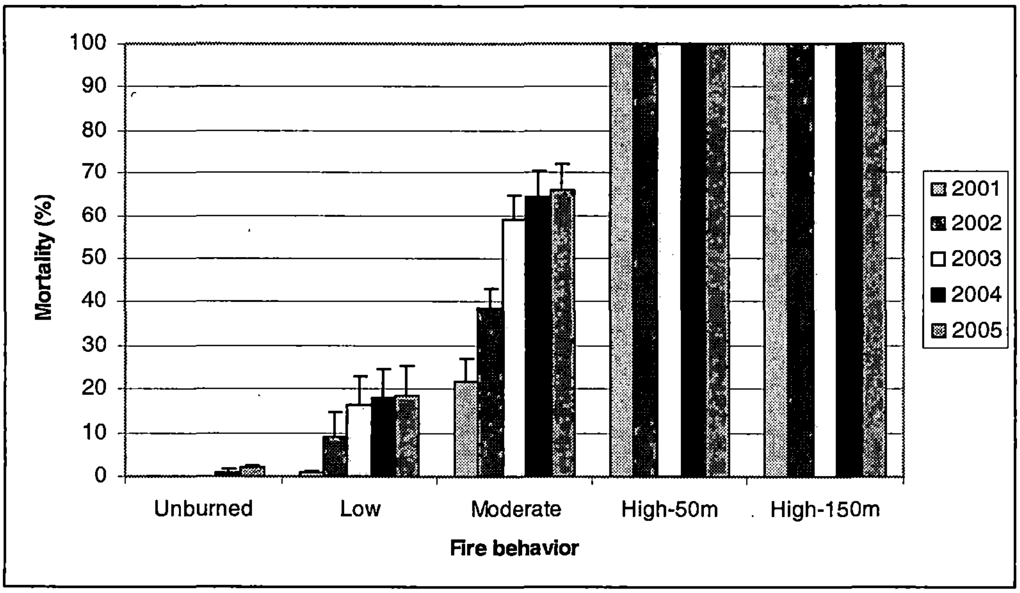

Fig. 4. Tree mortality (% of prefire stand density) (mean ± 1 SE) in areas of different fire behavior.

In 2002, the average stand diameter (SE) of a live tree was 23.0(1.2) and 27.1(1.2) cm in areas of low and moderate fire behavior. In 2002, the average diameter (SE) of a dead tree was 13.0(2.4) and 18.2(18) cm in areas of low and moderate fire behavior. The relationship between tree survivability and size persisted two years post-fire; however, three years post-fire, tree mortality was independent of tree size. In 2003, the average diameter of a live tree was 23.3(1.1) and 27.0(0.8) cm in areas of low and moderate fire behavior. In 2003, the average diameter of a dead tree was 16.6(2.2) and 22.0(0.9) cm in areas of low and moderate fire behavior. In 2004, the average diameter of a live tree was 23.3(1.1) and 27.1(0.9) in areas of low and moderate fire behavior whereas the average diameter of a dead tree was 17.0(2.2) and 22.5(1.0) cm in areas of low and moderate fire behavior. Tree diameters were remeasured in 2005. The average stand diameter of a live tree, therefore, reflects tree growth from 2001 through 2005 as well as the increase in average stand diameter due to fire selectively killing smaller diameter trees. In 2005, the

average stand diameter (SE) of a live tree in areas of low and moderate fire behavior was 24.2(1.1) and 27.6(1.0) while the average stand diameter of a dead tree in areas of low and moderate fire behavior in 2005 did not change from that in 2004 **(Fig. 5)**.

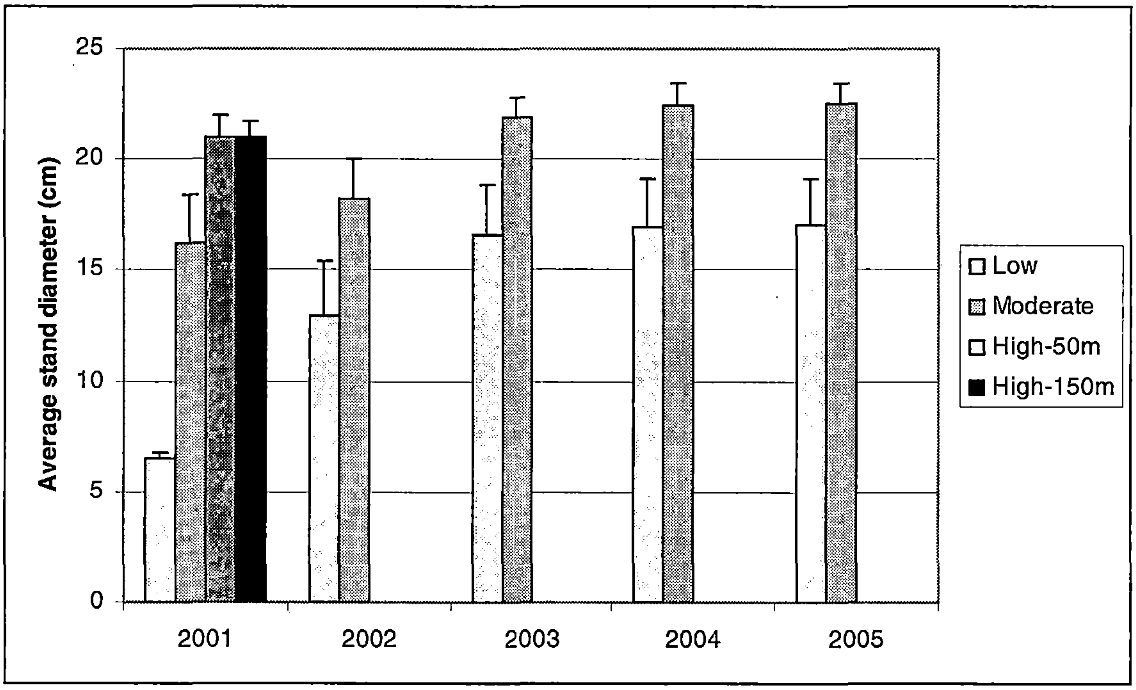

Fig. 5. Average stand diameter (mean ± 1 SE) of all dead trees within sites in areas of different fire behavior.

In general, insect activity intensified within and around the fire perimeter, with a substantial increase in insect activity in areas of moderate and high fire behavior. In 2001, we observed 4% of live trees in unburned and low fire behavior areas and 10 % of live trees in areas of moderate fire behavior with evidence of insect activity Insect activity in 2001 was limited to wood borer infestations. In 2002, we observed 5% of live trees in unburned areas and 3 and 40% of trees in areas of low and moderate fire behavior with evidence of insect activity. Recorded insect activity in 2002 throughout low and moderate fire severity areas included wood borer and red turpentine activity. Approximately 55% of the dead trees in areas where extreme or high fire behavior occurred had evidence of wood borer and(or) red turpentine infestations. In 2003, we observed 8% of live trees in unburned areas and 16 and 47% of trees in areas of low and moderate fire behavior

with evidence of insect activity. This year (2003) was the first year in which mountain pine beetle activity on study trees was observed. Mountain pine beetle activity was localized with only 1 tree in low fire behavior sites and 3 trees in moderate fire behavior sites possessing symptoms (pitch tubes) of a mountain pine beetle infestation. In areas of high severity fire, ~54% of the dead trees had evidence of insect activity with wood borer infestations accounting for ~44% of insect activity. In 2004, we observed 4% of live trees in unburned areas and 14 and 58% of trees in areas of low and moderate fire behavior with evidence of insect activity. Most insect activity was related to wood borer infestations on recently killed trees. We observed mountain pine beetle activity in the form of pitch tubes on only 1 study tree in 2004 and that occurred within a moderate fire behavior site. In areas of high fire behavior, we saw a high rate of insect activity with 79% of the fire killed trees having evidence of wood borer or red turpentine activity. During the 2005 field season, only signs of mountain pine beetle infestation were recorded. Similar to other years, mountain pine beetle activity on the study sites was low with only 1 tree in a moderate severity site possessing evidence of a mountain pine beetle infestation.

Fire directly and indirectly influences seedbed conditions through physical removal of overstory, understory, and forest floor components and by increasing soil moisture, soil temperature, and nutrient availability. We measured canopy light interception, cone production, seed production, and seedling regeneration to better understand the potential for post-fire tree regeneration.

One year after the fire, 40(8), 52(6), 74(4) % of full sunlight (SE) reached the forest floor through canopies affected by low, moderate, and high-0m fire behavior **(Fig. 6).** High-0m sites were located in areas adjacent to the live edge where fire behavior transitioned from moderate to high. In high-50m and high-150m sites 77(6) and 70(6) % of full sunlight (SE) reached the forest

floor. Light readings in high-50m and high-150m sites demonstrate bole shading as opposed to canopy interception of sunlight as snags in these interior high severity sites were the only source of shade throughout the sites. In 2001, throughout unburned stands, 25(3) % of full sunlight (SE) reached the forest floor. In 2002, light penetration increased throughout all fire behavior classes. In areas of low and moderate fire behavior there was between ~7 and 8% more sunlight reaching the forest floor than in 2001 due to the dropping of scorched needles as well as increased canopy openings due to fire-induced mortality. In high fire behavior sites located adjacent to the live edge, the percentage of sunlight reaching the forest floor remained unchanged from 2001. Interior high severity sites (high-50m and high-150m) were not measured in 2002 as all trees were directly killed by the fire in 2000. By 2003, significant canopy openings due to tree mortality allowed for greater light penetration throughout the burned pine stands. Light penetration in pine stands experiencing low severity had an increase of 3% greater light penetration whereas moderate severity sites saw an increase of ~12% more sunlight penetration than in 2002. In high severity pine stands, the fire killed snags were beginning to fall causing a decrease in bole shading and an increase in light penetration. High severity sites had, on average, 81% of the full sunlight reaching the forest floor. By 2004 and 2005, most fire caused tree mortality had ceased. There were not, therefore, large increases in the amount of sunlight reaching the forest floor, especially in low and moderate fire severity sites. Five years postfire, ~60(5), 78(5), 87(4), 93(1), and 90(3)% of full sunlight reached the forest floor in low, moderate, and high severity sites (high-0m, high-50m, and high-150m), respectively compared to 44(5)% in unburned pine stands.

The fire created opportunities for seedling establishment through disruption of the canopy and the forest floor; however, seed production was reduced both directly and indirectly by the fire. One year post-fire, we observed a higher proportion of trees with cones in burned areas than in

unburned areas; however, seed production was greater in unburned areas than in burned areas. In 2001 through 2005 8, 4, 32, 7, and 15% of trees in unburned areas had cones. We found cones on 5, 15, 40, 12, and 22 % of live trees in areas of low fire behavior 1, 2, 3, 4, and 5 years postfire. In areas affected by moderate severity fire, we found cones on 14, 10, 34, 13, and 39% of live trees in areas of moderate fire behavior 1, 2, 3, 4, and 5 years after the Jasper fire.

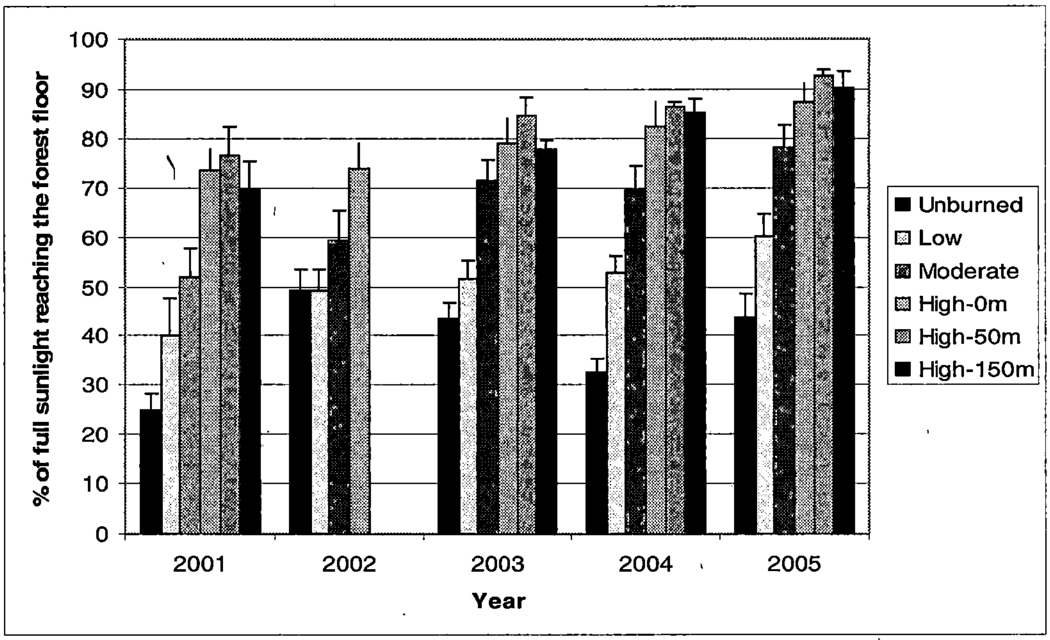

Fig. 6. The percentage of full sunlight (mean ± 1 SE) reaching the forest floor in areas of different fire behavior in ponderosa pine stands with no postfire silvicultural activities.

The number of potentially viable seeds captured from 2001 seed production was, on average, ~87% greater in unburned areas than in burned areas. Based on seeds recovered from traps protected from predators one year post-fire, seed density per hectare was ~112515, 57265, 42747, 89528, and 100819 in areas experiencing low, moderate, high-0m, high-50m, and high-150m fire behavior **(Fig. 7)**. These densities reflect a 25, 62, 72, 41, and 33 % reduction in seed production one year post-fire in areas of low, moderate, high-0m, high-50m, and high-150m fire behavior compared to unburned pine stands. Based on seeds recovered from traps protected from predators two years post-fire (collected in 2003), seed density per hectare was ~15325, 7259, 2420, 25810,

and 12098 in areas of low, moderate, high-0m, high-50m, and high-150m fire behavior. These seed densities reflect a 12% increase, a 47% decrease, an 82% decrease, an 88% increase, and a 12% decrease in seed production in areas of low, moderate, high-0m, high-50m, and high-150m fire behavior compared to seed densities observed in unburned pine stands. During the 2002 seed fall (collected in 2003), 63% of seeds were predated in areas of low fire behavior. In comparison, 100% of seeds were predated in areas of moderate and high (0, 50, and 150m from live edge) fire behavior. Based on seeds recovered from traps protected from predators four years postfire (2003 seed crop), seed density per hectare was ~291167, 339099, 136711, 37202, 807, and 0 in areas of unburned, low, moderate, high-0m, high-50m, and high-150m fire behavior. On average, 59% of seeds from the 2003 seed crop were predated in areas of low fire behavior and 42% were predated in areas of moderate fire behavior. There was 100% predation of the 2003 seed crop in areas of high (0, 50, and 150m from live edge) fire behavior. The 2004 seed crop which was collected in 2005 was highly variable throughout burned and unburned pine stands. In 2005, seed density calculated from traps protected from predators was approximately 16 times greater in areas of low fire behavior and 33% greater in areas of moderate and high-0m fire behavior than in unburned pine stands. During the 2004 seed fall (collected in 2005), ~36% of seeds in areas of low fire behavior and 33% of seeds in high-0m fire behavior were predated. We recorded no predation in areas of unburned, moderate, high-50m and high-150m fire behavior. No viable seeds were recorded from protected seed traps in the interior (high-50m and high-150m) high fire behavior sites; however 806 and 3225 viable seeds ha^{-1} were retrieved from seed traps open to predation.

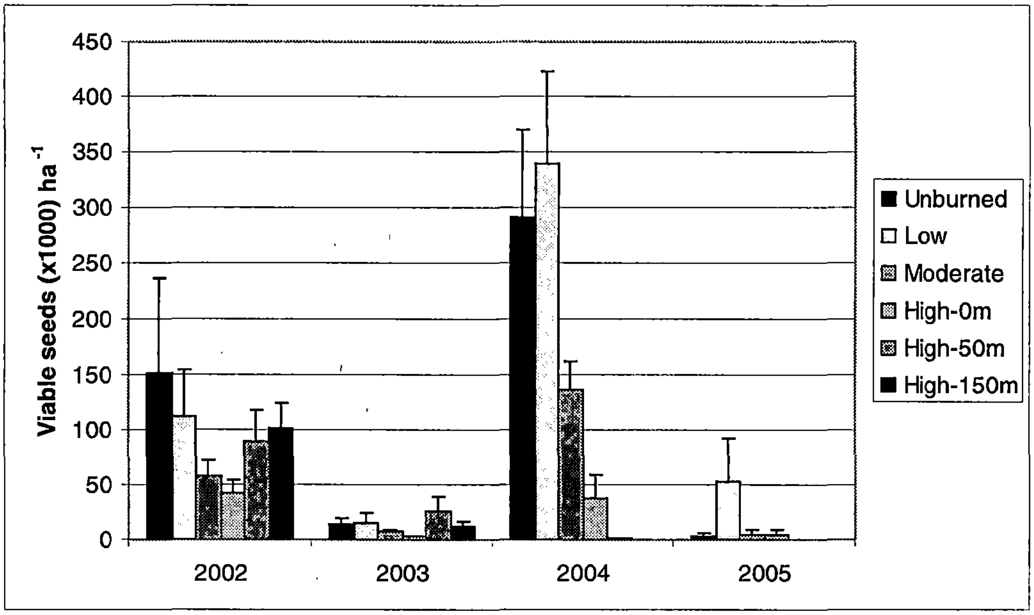

Fig. 7. Viable seed production from seed traps protected from predators (mean ± 1 SE) resulting from the 2001, 2002, 2003, and 2004 seed crop in post-fire in ponderosa pine stands with no postfire silvicultural activities.

In addition to a good seed crop, proper seedbed conditions are needed for natural regeneration to be successful. Postfire ponderosa pine variation was highly variable throughout all five years of the study **(Fig. 8)**. Drought, years of low seed production, and variability among geographic regions are possible mechanisms influencing regeneration following the Jasper fire. In 2001, we observed an average of 13089(5387), 1156(687), 1067(579), 711(345), 67(47), and 22(22) pre- and postfire germinant ponderosa pine seedlings ha^{-1}(SE) in areas of unburned, low, moderate, high-0m, high-50m, and high-150m severity. In 2002, we observed an average of 800(462), 1267(599), 2311(631), 511(342), 200(94), and 22(22) postfire germinant pine seedlings ha^{-1}(SE) in areas of unburned, low, moderate, high-0m, high-50m, and high-150m severity. In 2003, we observed an average of 5533(4658), 578(382), 533(273), 266(141), 0, and 22(22) postfire germinant seedlings ha^{-1}(SE) in areas of unburned, low, moderate, high-0m, high-50m, and high-150m severity. In 2004, we observed an average of 4733(2103), 760(3297), 3422(1574), 1511(1511), 222(222), and 22(22) postfire germinant seedlings ha^{-1}(SE) in areas of unburned, low, moderate,

high-0m, high-50m, and high-150m severity. In 2005, there was an average of 9089(4101), 2133(752), 1467(531), 222(135), 0, and 44(29) postfire germinant seedlings ha^{-1}(SE) in areas of unburned, low, moderate, high-0m, high-50m, and high-150m severity.

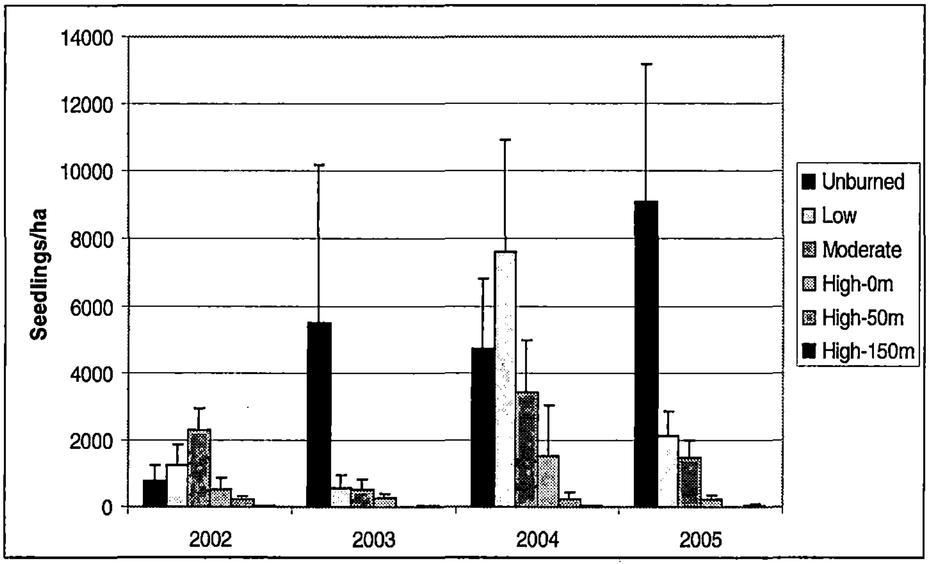

Fig. 8. Regeneration densities (mean ± 1 SE) in areas of different fire severity. Seedling density reflects only postfire ponderosa pine germinants.

2) Fire effects and recovery on the forest floor

We indexed fire behavior as the product of the proportion of the ground area charred and the degree of char scaled from low (1) to high (3). Burn index (SE) was 115 for low and 246 for high fire behavior on a scale of 100 to 300 **(Fig. 9)**. Burn index was statistically different in areas of different fire behavior ($p<0.05$).

One year post-fire, total forest floor depths (SE) were 5.4(0.3) cm in unburned stands and 1.2(0.2), 0.5(0.1), and 0.2(0.1) cm in areas of low to high fire behavior **(Fig. 10)**. Litter mass (SE) ranged from 1266 (198) g m^{-2} in unburned areas to 82 (20) g m^{-2} in areas that experienced high fire behavior. Duff constituted 27 and 30 % of the total forest floor in low and moderate severity areas, as contrasted with 51% in unburned stands. Litter constituted the remaining 73 and 70% of the total forest floor in areas of low and moderate fire behavior and 49% in unburned pine stands. Total

forest floor depth was statistically different when comparing unburned and burned areas ($p<0.05$) and in areas of different fire behavior ($p<0.05$).

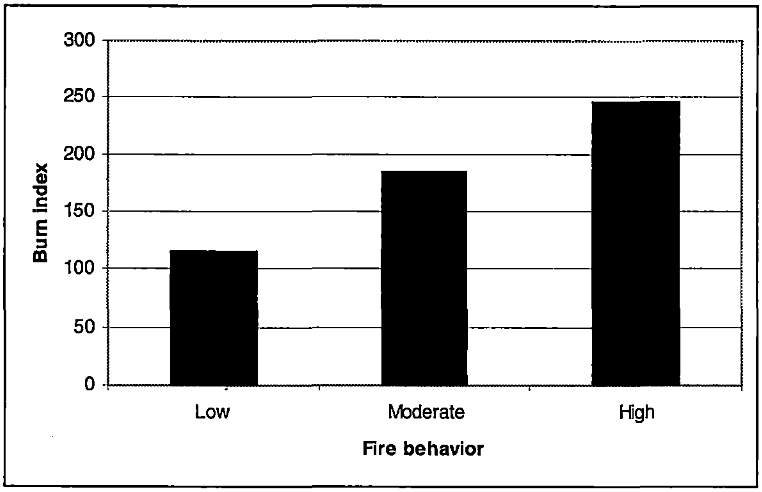

Fig. 9. Burn index under different fire behaviors in unmanaged ponderosa pine stands.

Two years post-fire, forest floor depths (SE) were 5.2(0.2) cm in unburned stands and 1.9(0.2), 1.7(0.2), and 0.2(0.1) cm in areas of low, moderate, and high fire behavior. Forest floor depth was 63 and 297% greater in areas of low and moderate fire behavior in the 2002 assessment than in the 2001 assessment. In 2002, litter made up a substantially greater percentage of the total forest floor depth than in 2001 due to the fall of scorched needles. In 2002, litter constituted 84% and 94% of the total forest floor depth in areas of low and moderate fire severity compared to 46% in unburned pine stands. Litter mass (SE) was 2219(299) g m^{-2} in unburned areas and was 598(64), 512(49), and 70(17) g m^{-2} in areas of low, moderate, and high fire behavior. Litter depth and mass were statistically different when comparing unburned and burned areas ($p<0.05$) and in areas of different fire behavior ($p<0.05$).

Three years post-fire, forest floor depths (SE) were 4.7(0.3) cm in unburned stands and 2.1(0.3), 2.1(0.1), and 0.4(0.1) cm in areas of low, moderate, and high fire behavior. Litter mass (SE) was 2770(270) g m^{-2} in unburned areas to 861(141), 964(178), and 321(50) g m^{-2} in areas of low, moderate, and high fire behavior. Bark and small branch material constituted the majority of

the litter mass in high severity pine sites. As a percentage of the total forest floor, litter made up slightly less of the total depth in 2003 than in 2002 in areas of low and moderate fire severity suggesting that duff was beginning to accumulate in these stands.

Four and five years post-fire, total forest floor depths (SE) were 4.7(0.3) and 5.1(.3) cm in unburned stands, 2.5(0.1) and 2.6(.1) in areas of low fire behavior, 2.2(0.1) and 2.1(.2) in areas of moderate fire behavior, and 0.3(0.1) and 0.2(.1) cm in areas of high fire behavior. In 2005, litter mass (SE) was 2654(181) g m^{-2} in unburned areas and 846(103), 777(66), and 94(30) g m^{-2} in areas of low, moderate, and high fire behavior. By 2005, litter constituted considerably less of total forest floor, as a percentage of the total forest floor, than in the previous four years in burned pine stands, but substantially more than in unburned stands suggesting that duff formation and accumulation is ongoing (albeit slowly) in burned stands. In 2005, litter comprised 78% of the total forest floor in areas of low fire severity and 81% of the total forest floor depth in areas of moderate fire severity compared to 53% in unburned pine stands. Overall, forest floor depth was 49%, 59%, and 96% lower in areas of low, moderate, and high fire behavior than in similar unburned stands.

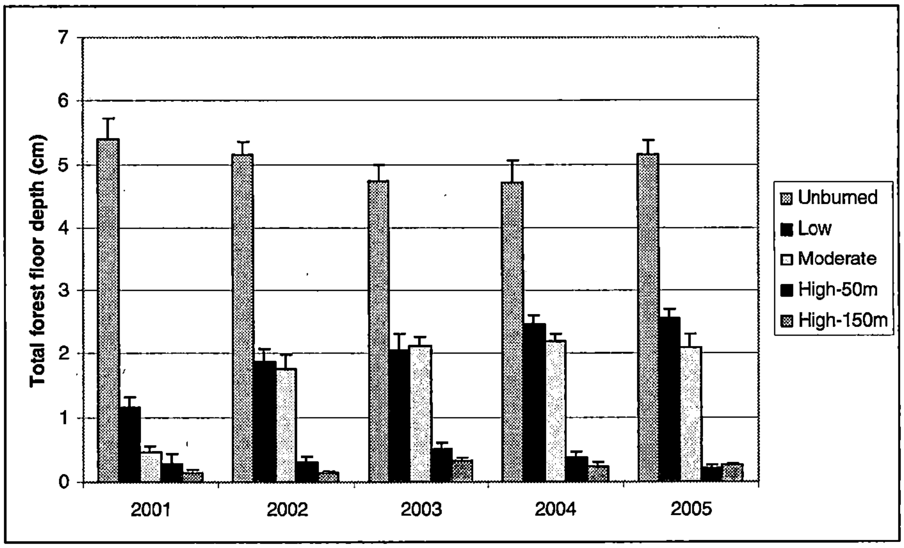

Fig. 10. Total forest floor depth (litter + duff) (mean ± 1SE) in ponderosa pine stands receiving no postfire management one, two, three, four and five years post-fire in areas of different fire behavior.

3) Fire effects and recovery of forest soils

We observed differences in soil texture, total carbon, and total and available nitrogen content in burned and unburned areas; however, only subtle differences were observed in areas affected by different fire behavior. It is often difficult to detect changes in soil physical and chemical properties where the organic layer is not entirely consumed, as was the case in areas affected by low and moderate fire behavior. The greatest changes in soil composition were observed in severely burned areas. As a result, information about the physical and chemical composition of burned soils was averaged across areas of different fire behavior for comparison with unburned soils.

Following fire, total organic carbon and nitrogen were reduced as compared to unburned areas, however, the amount of nitrogen available for plant uptake increased substantially. We assessed total C and total N one and two years post-fire with little annual variability in results. The two year average of total soil carbon (SE) in unburned and burned soils was 1204.8(162.4) and 873.8(68.2) g m^{-2} to a depth of 10 cm. Organic carbon was 27% lower in burned than in unburned soils. Organic nitrogen was 15% lower in burned soils than in unburned soils. The two year average of total soil nitrogen in unburned and burned soils was 58.3(9.0) and 49.5(4.2) g m^{-2} to a depth of 10 cm. Total carbon was significantly different in unburned and burned areas ($p<0.05$). The five year average of total nitrogen available to plants in the form of nitrate and ammonium was ~3.2 times greater in burned than in unburned areas **(Fig. 11)**. Nitrate was ~5.3 times greater in burned than unburned areas and ammonium was ~58% greater in unburned than in burned areas.

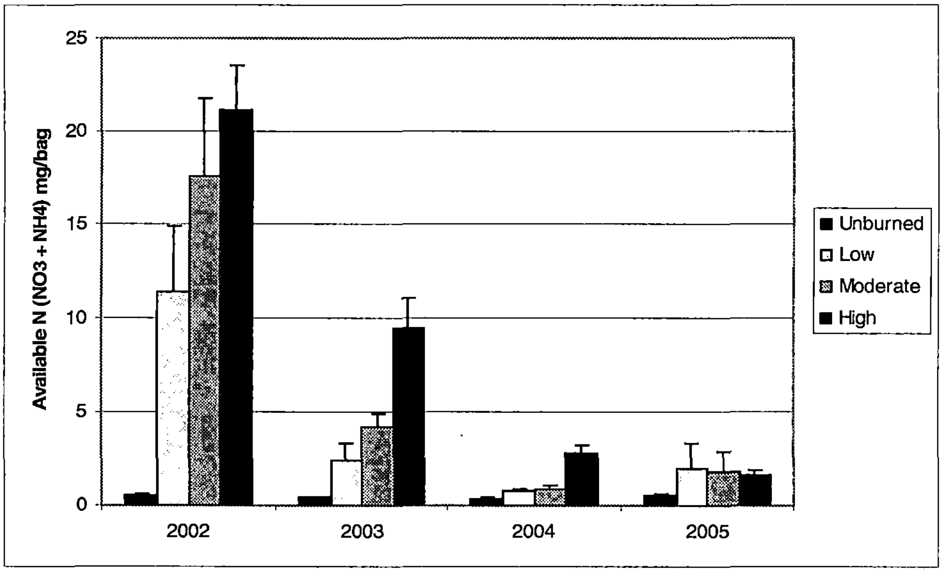

Fig. 11. Available total soil nitrogen (nitrate + ammonium) (mean ± 1SE) calculated from resin bags placed in ponderosa pine stands receiving no postfire management.

We calculated an index of erosion from midslope positions in burned areas. Greater soil movement was recorded in areas of high fire behavior. Mean soil gain (SE) was 0.1 (0.2), 0.2(0.2), and 0.8(0.2) cm in areas of low, moderate, and high fire behavior. Approximately 13 and 5 times more soil was moved into areas of high fire behavior as compared to areas of low and moderate fire behavior **(Fig. 12)**.

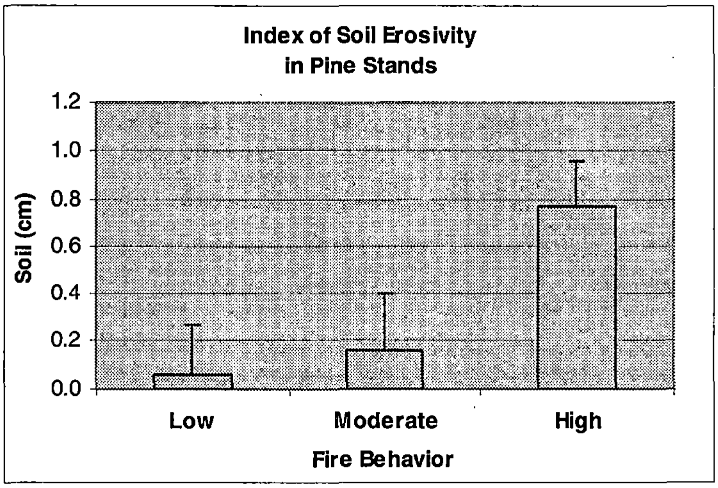

Fig. 12. Soil movement in areas of different fire behavior in pine stands.

4) Fire effects and recovery in the understory

How does post-fire understory (forbs, grasses, shrubs, and seedlings) compare in terms of species composition, percent cover, and dominance to unburned areas?

Plant cover increased dramatically during the first post-fire growing season. The 2001 late season estimates of plant cover in low and moderate severity treatments was 63 and 74% lower than pre-burn cover. Plant cover in high severity areas was 85% lower than pre-burn cover estimates. In 2001, total late season plant cover was 15 and 10% in low and moderate treatments, and 6% in high severity treatments. Forbs and grasses tended to provide most of the plant cover in early season burned treatments as aboveground shrub components were essentially removed by the fire. By the 2001 late season, shrubs had begun to recover. Grasses and forbs contributed ~9% of the cover in low and moderate severity areas and 2% cover in high severity areas. Shrubs contributed ~3% of the total cover in all burned areas.

In the second postfire growing season, early season total plant cover was substantially higher in unburned areas than in burned areas (**Table 3**). Early season plant cover in the most severely burned areas was 66% lower than the plant cover estimates from unburned areas. Total plant cover in unburned areas was 40%, and decreased from 20% in low severity treatments to 14% in high severity treatments. In 2002 in the early season, unburned sites were dominated by forbs (5%), shrubs (26%), grasses (8%), and seedlings (~1%). In the late season, unburned sites continued to have the highest total plant cover and were composed of forb cover (5%), shrub cover (44%), and grass cover (10%). In the late season, total plant cover was 33, 25, and 27% in areas affected by low, moderate, and high severity fire. Two years postfire, forbs and grasses contributed between 7 and 11% of the total plant cover in burned areas, and shrub cover increased with time since fire. In both years independent of fire severity, shrub cover was lower in burned than in unburned areas.

In the third postfire growing season, total plant cover was still substantially higher in unburned areas than in burned areas but had begun to approach the plant cover in unburned areas. Total plant cover in the pines stands experiencing extreme fire behavior was only 23% lower than the total plant cover observed in unburned areas. Total plant cover in unburned areas was 53% and decreased to 32% in low severity treatments to 35% in high severity treatments. In 2003, unburned sites were dominated by forbs (4%), shrubs (40%), grasses (7%), and seedlings (~2%). Three years postfire, forbs contributed between 5 and 13% of the total plant cover in burned areas, grasses contributed between 7 and 12% of the total plant cover, and shrub cover continued to increase with time since fire contributing between 13 and 24 % of the total plant cover.

By the 2005, total plant cover in burned pine sites approached levels observed in unburned areas, especially in areas that experienced moderate and high fire behavior. In 2005, total plant cover in unburned areas was 40%. By the fifth postfire growing season, total plant cover in the pines stands that experienced moderate and high fire behavior was only 7 and 6% lower than the total plant cover observed in unburned areas. In contrast, total plant cover in pine stands in the low severity treatment areas was still 27% lower than in unburned stands. In 2005, unburned sites were dominated by forbs (4%), shrubs (24%), grasses (8%), and seedlings (~3%). Five years post-fire, forbs contributed between 6 and 14% of the total plant cover in burned areas and grasses contributed between 11 and 14% of the total plant cover. Shrubs continued to dominate burned sites with shrubs contributing between 8 and 14 % of the total plant cover in burned areas.

Table 3. Total plant cover (%) in ponderosa pine stands receiving no postfire silvicultural activities.

Fire behavior	2001 (early season)	2002 (early season)	2003	2005
Unburned	39.7 (11.0)	40.3 (10.1)	52.9 (9.7)	40.2 (10.1)
Low	9.1 (2.2)	20.0 (3.5)	32.2 (7.7)	29.4 (4.8)
Moderate	5.1 (1.7)	14.2 (3.3)	34.9 (7.1)	37.3 (6.7)
High	3.0 (1.1)	13.5 (3.7)	40.8 (8.5)	37.8 (8.0)

In both years, we observed differences in species composition between burned and unburned areas and among areas that experienced different fire behavior; however differences in species richness were much less dramatic two years after the fire **(Table 4)**. In 2002, in unburned sites, we observed 11 shrub, 16 grass, and 49 forb species in the early part of the growing season. In comparison, in pine sites that experienced high or extreme fire behavior, we found 10 shrub species, 7 grass species, and 46 forb species in the early part of the growing season. In 2003, we observed the highest diversity in terms of forb species in sites that burned under high fire behavior. We observed 59 forb species in high severity sites as opposed to only 47 forb species in unburned sites. The number of grass species we observed in 2003 was similar among all unburned and burned sites (between 5 and 7 species). Similarly, shrub richness was similar among the unburned and burned sites with the sites that burned under moderate fire behavior possessing the greatest amount of shrub species among the burned sites. Similar to 2003, in 2005 we observed the greatest forb diversity in areas that burned under high fire behavior. We recorded 63 different forb species in high severity sites as opposed to ~40 different forb species in unburned, low, and moderate fire severity sites. Grass diversity was lowest in low severity sites and highest in moderate and high severity sites. Shrub richness was similar among all unburned and burned sites.

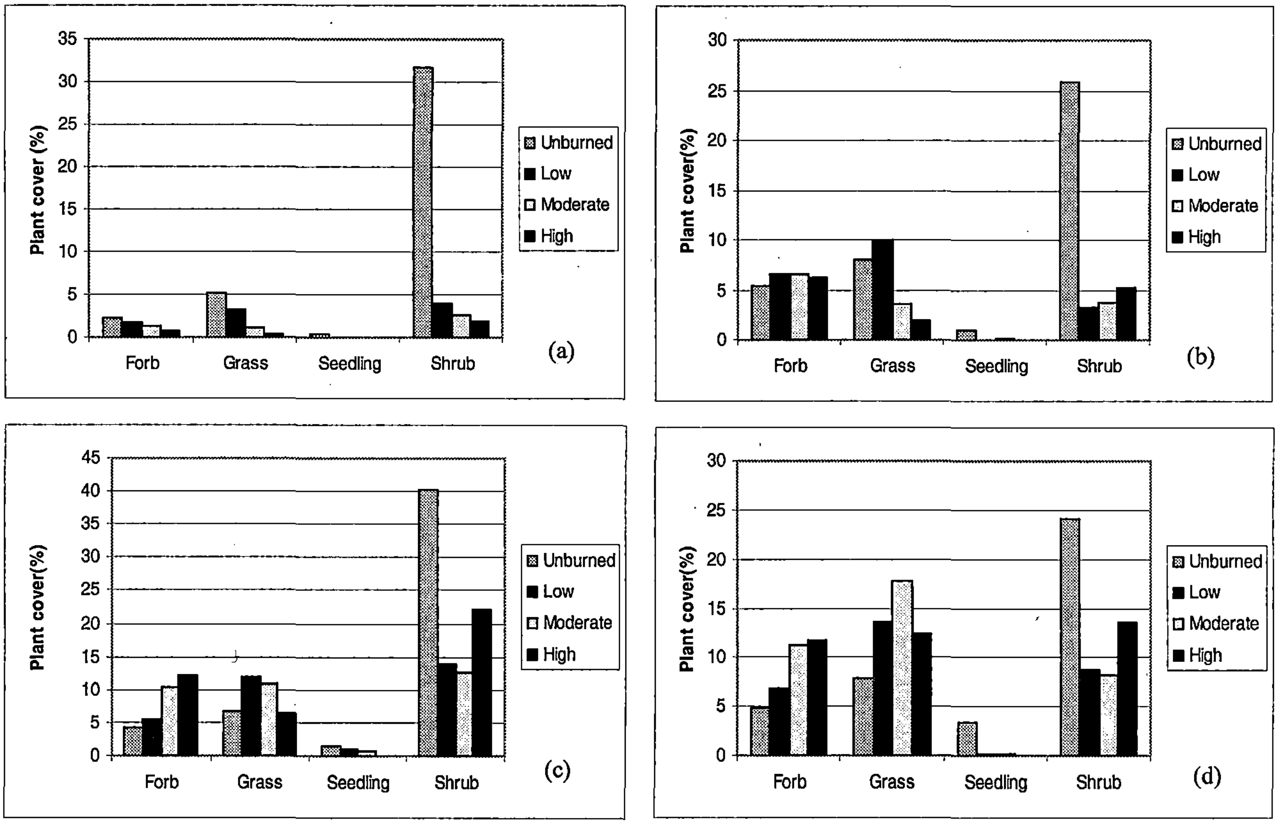

Fig. 13. The percent plant cover of each of the 4 functional groups in (a) 2001, (b) 2002, (c) 2003, and (d) 2005.

In the early season, herbaceous species richness was highest in areas that burned under low severity. In most cases, the number of species observed in the early season was as equal to or greater than the number observed in the late season in both burned and unburned areas. Herbaceous species richness was greater in unburned areas than in areas that burned under moderate and high severity in both the early and late season. Species richness was similar between unburned areas and those affected by low severity fire and between moderate and high treatments, suggesting that there may be a threshold of plant tolerance to fire severity.

We observed approximately 22 grass, 240 forb, and 10 shrub species in our study area throughout the 2001 growing season. Of these 2001 observations, 5 grass and 11 forb species are considered non-native. Non-native grass species observed includes *Phleum pratense*, *Poa compressa*, *Poa pratensis*, *Agrostis* sp., and *Elytrigia intermedia*. Non-native forb species observed

include *Alyssum desertorum, Camelina microcarpa, Taraxacum officianale, Thlaspi arvense, Tragopogon dubius, Trifolium hybridum, Trifolium pratense, Trifolium repens, Lactuca serriola, Vicia villosa, Epilobium angustifolium.* Of these non-native grass and forb species, *Phleum pratense, Poa compressa,* and *Poa pratensis,* and *Taraxacum officianale* were found in the four most dominant species in terms of cover for their species type. *Poa pratensis* was not observed in control treatments, but was found in low and moderate treatments. *Poa compressa* was found in control and moderate treatments, while *Phleum pratense* was found in control and all burned treatments. *Taraxacum officianale* was observed in unburned, low, and high severity treatments. The only noxious species observed in our study area was the forb, *Cirsium arvense.*

Table 4. Total number of forb, grass, and shrub species recorded in burned and unburned pine stands experiencing no postfire silvicultural activity.

Year	Unburned	Low	Moderate	High
2001 (early)	Forb: 33 Grass: 6 Shrub: 10	Forb: 33 Grass: 6 Shrub:	Forb: 21 Grass: 5 Shrub:	Forb: 23 Grass: 4 Shrub:
2001 (late)	N/A	Forb: 33 Grass: 6 Shrub: 6	Forb: 32 Grass: 5 Shrub: 7	Forb: 33 Grass: 3 Shrub: 6
2002 (early)	Forb: 49 Grass: 16 Shrub: 11	Forb: 53 Grass: 15 Shrub: 7	Forb: 39 Grass: 11 Shrub: 8	Forb: 46 Grass: 7 Shrub: 10
2002 (late)	Forb: 34 Grass: 16 Shrub: 13	Forb: 44 Grass: 22 Shrub: 10	Forb: 41 Grass: 11 Shrub: 8	Forb: 43 Grass: 9 Shrub: 11
2003	Forb: 47 Grass: 5 Shrub: 11	Forb: 54 Grass: 7 Shrub: 9	Forb: 49 Grass: 7 Shrub: 12	Forb: 59 Grass: 6 Shrub: 9
2005	Forb: 41 Grass: 15 Shrub: 9	Forb: 40 Grass: 10 Shrub: 8	Forb: 41 Grass: 16 Shrub: 7	Forb: 63 Grass: 16 Shrub: 7

We observed some overlap and differences in species composition among areas that burned under different fire severity from early to late season and between burned and unburned areas. Three forb species, *Balsamorhiza sagittata*, *Monarda fistulosa*, and *Dracocephalum parviflorum*, were observed as dominant species in terms of cover throughout the season. However, only *Monarda fistulosa* was recorded in unburned stands. The groundcover, *Antennaria neglecta*, common in unburned stands, was not observed in burned stands throughout the season. Three forb species, relatively sparse in the early season, *Apocynum androcaefolium*, *Chenopodium rubrum*, and *Chenopodium album*, were ranked high in terms of cover late in the season. Grass species composition was relatively similar between unburned and burned sites and within treatments throughout the season, with the exception of two species, *Leymus innovatus* and *Elymus trachycaulus*. These two species, previously absent in unburned and burned stands, were relatively dominant in terms of cover in low and moderate treatments late in the season.

The four most dominant shrubs throughout the 5-year study in unburned stands were *Juniperus communis*, *Arctostaphylos uva-ursi*, *Mahonia repens*, and *Symphoricarpus* spp. Two shrubs, *Juniperus communis* and *Lonicera dioica var glaucescens*, were observed only in unburned areas and not in burned areas. *Physocarpus monogynus* and *Potentilla fruticosa* were observed only in burned areas and not in unburned areas.

Preliminary results from assessments of post-fire germination vs. fire survivorship indicate that many species survived the fire and that the ability to regenerate from root stock provides a competitive advantage for these species. Preliminary results from assessments of post-fire germination vs. fire survivorship indicate that many species survived the fire and that the ability to regenerate from root stock provides a competitive advantage for these species. The species composition of the post-fire seed bank was dominated by grasses of the Carex and Poaceae families.

We identified 400 individuals with a high degree of species redundancy. With the exception of one herbaceous species, *Monolepis nuttaliana* (Chenopodaceae family), all species were documented in our vegetation surveys.

6) Fire Effects on Coarse Woody Debris

How much CWD was removed and eventually created under different fire intensities?

In 2001 in unmanaged, unburned areas, mean total fuel loadings were ~5 times greater than mean total fuel loadings in burned areas; however, the composition (fine vs. large) of fuels was relatively unchanged. In unburned areas, fine fuels (material < 7.62 cm in diameter) and coarse fuels (> 7.62 cm in diameter) comprised ~30% and 70% of total fuel weight. In burned stands of all fire intensities, fine fuels comprised between 17 and 47% of the total fuel load and coarse fuels comprised between 53 and 83% of the total fuel loading.

The average total fuel load in burned pine stands almost doubled from 2001 to 2002. In 2002, fuel loads remained relatively unchanged in unburned areas and in areas affected by low severity fire; however, fuel loadings increased dramatically in areas impacted by moderate and high severity fire. There was an ~66% and 125% increase in total fuel load between 2001 and 2002 in areas of moderate and high fire behavior, respectively.

In 2001, we observed ~32% more fuels in low severity areas as compared to those affected by high severity fire **(Fig. 14)**. In 2002 through 2005, we observed ~83, 72,128, and 352% more fuels in high severity than in low severity. In 2001, fuel loadings in moderate severity treatments were ~29% lower than in low severity treatments. Fuel loadings in moderate severity sites were equal to that in high severity treatments in 2001. By 2004, total fuel loadings in all treatments were considerably greater than in 2001 due to postfire snag fall. By 2004, fuel loads in areas affected by moderate fire behavior were 60% greater than in low severity treatments; however moderate

severity sites had ~30% lower total fuel loadings than high severity sites. Between 2004 and 2005 the total fuel load in all treatment areas continued to increase with the greatest increase in dead and downed material in the high-50m and high-150m areas. In 2005, for the first time since the fire, fuel loadings (fine + coarse fuels) in moderate and high severity treatments were equal to or greater than fuel loadings in unburned pine sites.

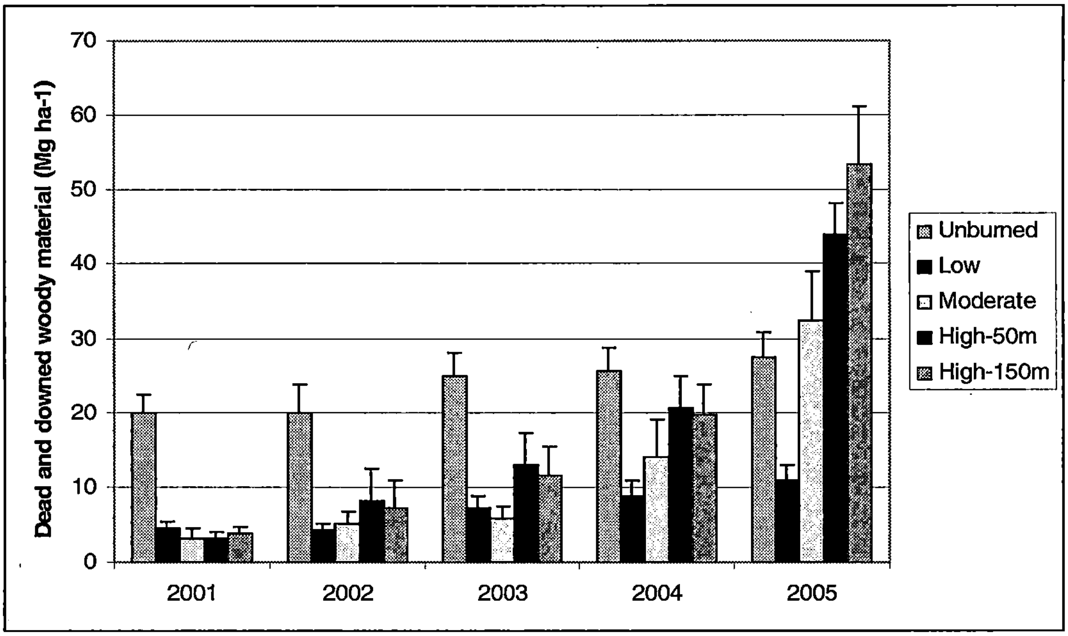

Fig. 14. Total downed woody debris (Mg ha^{-1}) (mean ± 1SE) in ponderosa pine stands affected of different fire behavior.

References

Binkley, D., Carter, R. and Allen, H.L., 1995. Nitrogen fertilization practices in forestry. In: P.E. Bacon (Editor), Nitrogen Fertilization in the Environment. Marcel Dekker, Inc, New York, pp. 421-441.

Brown, J.K., 1974. Handbook for inventorying downed woody material. GTR-INT-16, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Brown, J.K., Oberheu, R.D. and Johnston, C.M., 1982. Handbook for inventorying surface fuels and biomass in the interior west. GTR-INT-129, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Brown, J.K. and Roussopoulos, P.J., 1974. Eliminating biases in the planar intersect method for estimating volumes of small fuels. Forest Science, 20(4): 350-356.

DeBano, L.F., Neary, D.G. and Ffolliott, P.F., 1998. Fire's Effects on Ecosystems. John Wiley and Sons, New York, 318 pp.

Olson, J.S. 1963. Energy Storage and the Balance of Producers and Decomposers in Ecological Systems. Ecology, 44 (2): 322-331.

Ryan, K.C. and Noste, N.V., 1983. Evaluating prescribed fires. GTR-INT-182, USDA Forest Service, Intermountain Forest and Range Experiment Station, Ogden, UT.

Thomas, J.W. (Editor), 1979. Wildlife habitats in managed forests: the Blue Mountains of Oregon and Washington. USDA Handbook 553, Washington D.C.

Turner, M.G. (Editor), 1987. Landscape Heterogeneity and Disturbance. Springer-Verlag, New York.

Turner, M.G., Hargrove, W.W., Gardner, R.H. and Romme, W.H., 1994. Effects of fire on landscape heterogeneity in Yellowstone National Park, Wyoming. Journal of Vegetation Science, 5: 731-742.

USDA, 1978. Field instructions - stand examination and forest inventory, Stand Examination Handbook FSH 2409.21, R1 Chapter 300. USDA Forest Service Region 1, Missoula, MT.

APPENDIX 1. Location of Study Sites

ASPEN SITES

CENTRAL ASPEN BASELINE

ASCBL 13 T 596887 4850319
Slope = 13.32% Aspect = 288°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 1.8 mi, turn left on FS284.2A, go 0.3 mi, stop at boulders. Site is 131°/64m on left(SE).

CENTRAL LOW SEVERITY ASPEN SITES

ASC1L 13 T 597279 4853336
Slope = 0.00% Aspect = 224°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go 1.8 mi, turn left on FS472, go 1.0 mi. Site is CUT on left side of road.

ASC2L 13 T 597315 4855613
Slope = 6.00% Aspect = 156°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go 3.0 mi, turn left on FS469 for 0.1 mi, turn left on FS469.1G for 0.2 mi. Site is 15m on left.

ASC3L 13 T 596768 4850222
Slope = 30.24% Aspect = 334°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 1.8 mi, turn left on FS284.2A, go 0.3 mi, stop at boulders. Site is 199°/0.16km on left.

CENTRAL HIGH SEVERITY ASPEN SITES

ASC1H 13 T 597179 4853260
Slope = 7.28% Aspect = 146°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go 1.8 mi, turn left on FS472, go 1.05 mi. Site is CUT on right side of road.

ASC2H 13 T 596939 4855560
Slope = 15.00% Aspect = 10°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go 3.0 mi, turn left on FS469 for 0.1 mi, turn left on FS469.1G for 0.4 mi. Site is 186°/43m on left side of road.

ASC3H 13 T 59FS6813 4850223
Slope = 30.00% Aspect = 323°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 1.8 mi, turn left on FS284.2A, go 0.3 mi, stop at boulders. Site is 182°/0.13km on left.

NORTHERN ASPEN BASELINE

ASNBL 13 T 587900 4860914
Slope = 5.00% Aspect = 76°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go ~7.5 mi, turn left on FS296, go ~8.9 mi. (0.1 km past junction of FS296 & FS289). Site is FS289°/0.36 km on left.

NORTHERN LOW SEVERITY ASPEN SITES

ASN1L 13 T 586434 4858428
Slope = 13.00% Aspect = 92°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 4.4 mi, turn right on FS289, go 0.5 mi, turn right on FS289.1B, go 0.6 mi. Site is 246°/97m on left.

ASN2L 13 T 590925 4858726
Slope = 9.33% Aspect = 132°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go ~7.5 mi, turn left on FS296, go ~5.6.0 to junction with FS383 and park. Site is 67°/0.16km on right.

ASN3L 13 T 591511 4858917
Slope = 16.59% Aspect = 349°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go ~7.5 mi, turn left on FS296, go ~5.0 mi to junction with FS291.1K. Site is 306°/81m from junction of FS296 and FS296.1K on right.

NORTHERN HIGH SEVERITY ASPEN SITES

ASN1H 13 T 586754 4858093
Slope = 21.00% Aspect = 296°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 4.4 mi, turn right on FS289, go ~0.5 mi, turn right on FS289.1B, go 0.3 mi. Site is 129°/86m on right.

ASN2H 13 T 590616 4858900
Slope = 8.00% Aspect = 41°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go ~7.5 mi, turn left on FS296, go ~5.9mi. Site is 356°/70m on right.

ASN3H 13 T 591903 4858389
Slope = 6.34% Aspect = 337°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go ~7.5 mi, turn left on FS296, go ~5.0 mi to junction with FS291.1K. Turn left on FS291.1K and go 0.3 mi. Site is 162°/0.11km on left.

Montane Grassland Sites

<u>**MONTANE GRASSLAND BASELINE**</u>

MGBL 13 T 594928 4861257

Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go ~6.5 mi, turn right onto FS291.3L (693) for 0.1 mi. Site is on left side of road on top of hill.

<u>**GILLETTE CANYON**</u>

MGGC1 13 T 586985 4860177

Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go ~7.5 mi, turn left on FS296, go ~7.5mi (0.1 mi after FS296.1H), turn left into grasslands and go 1.0 mi. Site is on right.

MGGC2 13 T 590471 4859511

Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go ~7.5 mi, turn left on FS296, go ~5.9mi. Turn right on FS296.1C, go 0.4 mi, veer right down into grassland for 0.2 mi. Site is on left

MGGC3 13 T 592529 4860243

Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go ~7.5 mi, turn left on FS296, go ~3.5mi. Site is on right.

<u>**LEMMING DRAW**</u>

MGLD1 13 T 595706 4858085

Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go ~3.6 mi, turn right on FS383, go ~0.8 mi, park at Lemming Draw. Site is 24°/3.4 mi on right.

MGLD2 13 T 595331 4855820

Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go ~3.6 mi, turn right on FS383, go ~0.8 mi, park at Lemming Draw. Site is 25°/1.5 mi on right.

MGLD3 13 T 595326 4855048

Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go ~3.6 mi, turn right on FS383, go ~0.8 mi, park at Lemming Draw. Site is 29°/1.5 mi on right.

Ponderosa Pine Sites

SOUTHERN MONITORING-CONTROL BASELINE SITES

S1BL **13 T 588043 4841138**
Slope = 13.00% Aspect = 48°
Go west on H-way 16, go ~12.5 mi, turn left on FR270, go 2.2mi, turn right on FS271, go 0.8 mi and park near large boulder. Site is 15°/0.17 km on right.

S2BL **13 T 589723 4840864**
Slope = 17.00% Aspect = 350°
Go west on H-way 16, go ~12.5 mi, turn left on FR270, go 1.4mi and park. Site is 336°/0.2 km on right.

S3BL **13 T 584781 4843536**
Slope = 13.00% Aspect = 79°
Go west on H-way 16, go ~17 mi, turn right on FS668, go 2mi, turn left on FS281, go 1.2 mi, turn left on FS281.1C, go 1.1 mi, turn left on FS281.1T for 0.5 mi. Site is 256°/0.13 km on right.

SOUTHERN MONITORING-CONTROL LOW SEVERITY SITES

S1L **13 T 589405 4845600**
Slope = 12.50% Aspect = 170°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.2 mi into opening. Site is 346°/0.17km uphill on left.

S2L **13 T 590441 4846157**
Slope= 5.3% Aspect= 63°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.3 mi, turn left on FS282.1D, go 0.8 mi. Site is 307°/0.14km on left.

S3L **13 T 589852 4843947**
Slope = 12.00% Aspect = 300°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 1.0 mi, park and walk down streambed into clearing. Site is 185°/0.54km uphill on left.

SOUTHERN MONITORING-CONTROL MODERATE SEVERITY SITES

S1M 13 T 589671 4846085
Slope=9% Aspect= 240°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.3 mi, turn left on FS282.1D, go 0.2 mi into opening by guzzler. Site is 356°/0.39km uphill on left.

S2M 13 T 590280 4845648
Slope = 7.00% Aspect = 252°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.3 mi, turn left on FS282.1D, go 0.5 mi. Site is 172°/0.2km on right.

S3M 13 T 589920 4844115
Slope = 10.00% Aspect = 360°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 1.0 mi, park and walk down streambed into clearing. Site is 175°/0.39km uphill on left.

SOUTHERN MONITORING-CONTROL HIGH-0M SEVERITY SITES

S1H0 13 T 590528 4845090
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.6 mi to powerline. Site is 78°/0.71km uphill on left.

S2H0 13 T 590483 4844984
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.6 mi to powerline. Site is 88°/0.641km uphill on left.

S3H0 13 T 590335 4844784
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.6 mi to powerline. Site is 110°/0.52km uphill on left.

SOUTHERN MONITORING-CONTROL HIGH-50M SEVERITY SITES

S1H50 13 T 590446 4845094
Slope = 15.00% Aspect = 301°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.6 mi to powerline. Site is 76°/0.61km uphill on left.

S2H50 13 T 590411 4844980
Slope = 13.13% Aspect = 315°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.6 mi to powerline. Site is 87°/0.571km uphill on left.

S3H50 13 T 590264 4844811
Slope = 13.50% Aspect = 249°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.6 mi to powerline. Site is 110°/0.52km uphill on left.

SOUTHERN MONITORING-CONTROL HIGH-150M SEVERITY SITES

S1H150 13 T 590356 4845048
Slope = 7.00% Aspect = 347°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.6 mi to powerline. Site is 80°/0.52km uphill on left.

S2H150 13 T 590316 4844990
Slope = 16.40% Aspect = 258°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.6 mi to powerline. Site is 85°/0.47km uphill on left.

S3H150 13 T 590269 4844892
Slope = 20.30% Aspect = 188°
Go west on H-way 16 for ~13 mi, turn right on FS282, go 2.7 mi, veer left on FS283, go 1.0 mi, turn left on FS668, go1.0 mi, turn left on FS668.1A, go 0.6 mi, turn left on FS668.1D for 0.6 mi to powerline. Site is 98°/0.43km uphill on left.

CENTRAL MONITORING-CONTROL BASELINE SITES

C1BL **13 T 598530 4854236**
Slope = 18.36% Aspect = 281°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go 1.6 mi, park at junction of FS291 and FS293. Site is 352°/ 200 m on NE side.

C2BL **13 T 599150 4853745**
Slope = 17.00% Aspect = 123°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn right on FS291, go 0.9 mi, turn right on FS291.1A, go 0.4 mi. Site is 275°/85m on left.

C3BL **13 T 599591 4851878**
Slope = 21.00% Aspect = 232°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.5 mi, turn right on FS284.1I, go 0.1 mi and park. Site is 340°/0.18km on right.

CENTRAL MONITORING-CONTROL LOW SEVERITY SITES

C1L **13 T 592862 4848913**
Slope = 12.00% Aspect = 159°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 358°/0.61 km.

C2L **13 T 594062 4848758**
Slope = 6.28% Aspect = 240°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 2.8 mi, turn left on FS282.2K, go 0.5 mi and park. Site is 108°/0.36 km on right.

C3L **13 T 593157 4848111**
Slope = 13.00% Aspect = 66°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.4 mi, park on southeast side of road. Site is 127°/0.32 km on left.

CENTRAL MONITORING-CONTROL MODERATE SEVERITY SITES

C1M **13 T 592901 4848646**
Slope = 9.00% Aspect = 224°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 2°/0.33 km.

C2M **13 T 594335 4849448**
Slope = 11.01% Aspect = 329°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 2.8 mi, turn left on FS282.2K, go 0.8 mi to junction with FS284.2F. Site is 33°/0.43 km on left.

C3M **13 T 594207 4848710**
Slope = 5.05% Aspect = 145°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 2.8 mi, turn left on FS282.2K, go 0.5 mi and park. Site is 110°/0.5 km on right.

CENTRAL MONITORING-CONTROL HIGH-0M SEVERITY SITES

C1H0 **13 T 592040 4849341**
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 292°/1.19 km

C2H0 **13 T 592636 4848917**
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 304°/0.54 km.

C3H0 **13 T 592118 4849183**
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 301°/1.03 km.

CENTRAL MONITORING-CONTROL HIGH-50M SEVERITY SITES

C1H50 13 T 592111 4849355
Slope = 8.00% Aspect = 225°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 309°/1.24 km

C2H50 13 T 592609 4848986
Slope = 15.80% Aspect = 159°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 308°/0.62 km.

C3H50 13 T 592198 4849183
Slope = 11.00% Aspect = 189°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 307°/0.98 km.

CENTRAL MONITORING-CONTROL HIGH-150M SEVERITY SITES

C1H150 13 T 592226 4849369
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 310°/1.13 km

C2H150 13 T 592538 4849075
Slope = 6.30% Aspect = 185°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 311°/0.72 km.

C3H150 13 T 592303 4849194
Slope = 14.00% Aspect = 186°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.2 mi, park on west side of road. Site is 303°/1.06 km.

NORTHERN MONITORING-CONTROL BASELINE SITES

N1BL **13 T 585FS284 4860429**
Slope = 18.53% Aspect = 348°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.0 mi, turn right on FS284.5D, go 0.6 mi, turn right on FS284.2B for 0.7mi. Site is 199°/0.11km on left.

N2BL **13 T 581428 4861298**
Slope = 30 – 35% Aspect = 286°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 8.5 mi, turn right on FS284.5C, go 0.3 mi, veer left, go 0.7 mi on FS284.5C. Site is 104°/0.11 km uphill on right.

N3BL **13 T 579145 4859447**
Slope = 8.40% Aspect = 80°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 10.9 mi, turn left on FS117, go 0.9 mi and park on FS117.5V. Site is 220°/0.15km uphill on left.

NORTHERN MONITORING-CONTROL LOW SEVERITY SITES

N1L **13 T 583592 4859349**
Slope = 13.00% Aspect = 210°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.6 mi, turn left on FS284.5H for 0.3 mi. Site is 14°/0.14 km on right.

N2L **13 T 583850 4857703**
Slope = 8.78% Aspect = 353°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 5.2 mi, turn left on 280, go 0.3 mi, veer right onto 376, go 1.0 mi and park. Site is 4°/0.26km uphill on right.

N3L **13 T 583008 4858250**
Slope = 10.00% Aspect = 310°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I, go 0.3 mi to junction with FS284.5L. Site is 225°/0.71km along 2-track.

NORTHERN MONITORING-CONTROL MODERATE SEVERITY SITES

N1M **13 T 583442 4859505**
Slope = 11.00% Aspect = 258°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.6 mi, turn left on FS284.5H for 0.3 mi. Site is 337°/0.27 km on right.

N2M **13 T 584011 4857758**
Slope = 11.13% Aspect = 178°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 5.2 mi, turn left on 280, go 0.3 mi, veer right onto 376, go 1.0 mi and park. Site is 28°/0.39km uphill on right.

N3M **13 T 583053 4858115**
Slope = 10.00% Aspect = 168°Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I, go 0.3 mi to junction with FS284.5L. Site is 218°/0.79km along 2-track.

NORTHERN MONITORING-CONTROL HIGH-0M SEVERITY SITES

N1H0 **13 T 582476 4858426**
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I for 1.2 mi to junction of FS284.5I and FS284.5K. Site is 20 m on either side of road.

N2H0 **13 T 582408 4858285**
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I, go 1.4 mi and park at fenceline. Site is 29°/0.2km on left.

N3H0 **13 T 581971 4857512**
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I for 1.9 mi and park. Site is 0.11m on either side of road.

NORTHERN MONITORING-CONTROL HIGH-50M SEVERITY SITES

N1H50 13 T 582431 4858482
Slope = 35 – 40% Aspect = 289°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I for 1.2 mi to junction of FS284.5I and FS284.5K. Site is 312°/ 76m on right.

N2H50 13 T 582338 4858275
Slope = 30.95% Aspect = 291°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I , go 1.2 mi and park at fenceline. Site is 8°/0.16km on right.

N3H50 13 T 581907 4857541
Slope = 40.00% Aspect = 322°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I for 1.9 mi and park. Site is 266°/80.0m on right.

NORTHERN MONITORING-CONTROL HIGH-50M SEVERITY SITES

N1H150 13 T 582386 4858552
Slope = 35 - 40% Aspect = 289°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I for 1.2 mi to junction of FS284.5I and FS284.5K. Site is 319°/ 0.16km on right.

N2H150 13 T 582222 4858205
Slope = 25.00% Aspect = 312°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I, go 1.2 mi and park at fenceline. Site is 324°/0.15km on right.

N3H150 13 T 581843 4857578
Slope = 45.505 Aspect = 298°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 6.3 mi, turn left on FS284.5I for 1.9 mi and park. Site is 297°/0.15km on right.

PONDEROSA PINE RESTORATION SITES

SOUTHERN MODERATE SEVERITY RESTORATION SITES

RSS1M 13 T 596514 4845203
Slope = 10.00% Aspect = 260°
Go W on 16 for ~9mi, turn right on FS681, go 0.8 mi, turn left on FS680, go 0.6mi, veer left on FS680.1A, go 0.5mi. Site is 18°/35m on right.

RSS2M 13 T 595321 4844116
Slope = 26.00% Aspect = 85°
Go W on 16 for ~9mi, turn right on FS681, go 0.8 mi, turn left on FS680, go 0.5mi, turn left on FS680.1B, go 0.3mi, veer right, go 0.9mi. Site is 224°/0.53km on left. (Site is flipped-P1 is S, etc).

RSS4M 13 T 596695 4842984
Slope = 6.00% Aspect = 51°
Go W on 16 for ~9.5mi, turn left on 278, go 1.3mi. Site is 72°/0.41km uphill on right.

SOUTHERN HIGH SEVERITY RESTORATION SITES

RSSIH
Slope = 8.30% Aspect = 289°
Go W on 16 for ~9mi, turn right on FS681, go 0.8 mi, turn left on FS680, go 0.6mi, veer left on FS680.1A, go 0.5mi. Site is 212°/0.2km uphill on left.

RSS2H 13 T 594951 4844108
Slope = 6.50% Aspect = 246°
Go W on 16 for ~9mi, turn right on FS681, go 0.8 mi, turn left on FS680, go 0.5mi, turn left on FS680.1B, go 0.3mi, veer right, go 0.9mi. Site is 241°/0.85km on left.

RSS3H 13 T 596191 4843981
Slope = 27..00% Aspect = 210°
Go W on 16 for ~9mi, turn right on FS681, go 0.8 mi, turn left on FS680, go 0.5mi, turn left on FS680.1B, go 0.3mi, turn left on FS680.1D, go 1.0mi. Site is 262°/87m on left.

CENTRAL MODERATE SEVERITY RESTORATION SITES

RSC6M 13 T 597652 4850987
Slope = 25.00% Aspect = 82°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 1.4 mi, turn right on FS472, go <0.1 mi, turn right on 471, go 0.4mi and park. Site is 257°/55m on left.

RSC7M 13 T 597529 4850716
Slope= 18.00% Aspect = 166°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 1.4 mi, turn right on FS472, go <0.1 mi, turn right on 471, go 0.2mi and park. Site is 330°/48m on left.

RSC8M 13 T 594160 4846343
Slope= 8% Aspect= 180°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.6mi, turn left on FS282.1A, go 2.3mi. Site is 101°/68m on left.

CENTRAL HIGH SEVERITY RESTORATION SITES

RSC6H 13 T 596844 4849742
Slope = 16% Aspect = 286°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 1.8 mi, turn left on FS284.2A, go 0.8 mi, stop at landing. Site is 88°/0.37km on left.

RSC7H 13 T 597496 4850801
Slope = 15.00% Aspect = 326°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 1.4mi, turn right on FS472, go <0.2 mi and park. Site is 48°/90m on right.

RSC8H 13 T 594027 4846889
Slope= 4% Aspect= 272°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 4.0 mi, turn left on FS282, go 3.6mi, turn left on FS282.1A, go 2.0mi. Site is 258°/61m on right.

NORTHERN MODERATE SEVERITY RESTORATION SITES

RSN2M
Slope= 3%   Aspect= 193°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 4.4 mi, turn right on FS289, go ~3.7 mi. Site is 31°/0.1km on left.

RSN3M 13 T 585510 4859028
Slope= 11%   Aspect= 350°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 4.4 mi, turn right on FS289, go 0.3 mi, turn left on FS289.1A, go 0.9mi. Site is 0.97°/0.32km on left.

RSN4M 13 T 585231 4857829
Slope= 6%   Aspect= 81°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 4.8 mi, park on curve at big rocks. Site is359°/0.45km on right.

NORTHERN HIGH SEVERITY RESTORATION SITES

RSN2H 13 T 586574 4859925
Slope= 3%   Aspect= 83°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 4.4 mi, turn right on FS289, go ~2.4 mi. Site is 307°/0.6km on left.

RSN3H 13 T 585455 4858905
Slope= 13%   Aspect= 326°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 4.4 mi, turn right on FS289, go 0.3 mi, turn left on FS289.1A, go 0.9mi Site is 0.123°/0.31km on right.

RSN4H 13 T 585171 4857616
Slope= 12%   Aspect= 206°
Go N on FS288 for 5.5 mi, turn left on FS284, go 0.8 mi, turn left on FS284, go 7.1 mi, turn right on FS284, go 4.8 mi, park on curve at big rocks. Site is 345°/0.23km on right.